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Post-Fire Soil Erosion and How to Manage It

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Fire Science Brief

RESEARCH SUPPORTING SOUND DECISIONS

Helicopter spraying with hydromulch was one of the methods of controlling post-fire erosion which was studied. Findings will provide guidance on best methods of controlling erosion after both wildfires and prescribed burns.

Post-Fire Soil Erosion and How to Manage It

Summary

A pair of major wildfires in the Front Range of Colorado in 2002 created an ideal opportunity to measure post-fire soil erosion characteristics and to assess the effectiveness of various site rehabilitation treatments to reduce erosion. The studies continued over a four-year period, allowing collection of data on longer-term erosion and sedimentation trends. Most erosion in this region is caused by localized convective thunderstorms rather than snowmelt runoff.

Sedimentation measurements documented that straw mulch and to a limited extent hydromulch were effective in reducing post-fire erosion by increasing the amount of ground cover. Seeding following scarification and application of a polyacrylamide (PAM) spray had little to no effect on post-fire erosion rates. Erosion in the fire study areas in some cases has not yet returned to background levels. Percentage of ground cover was shown to be the predominant control on post-fire erosion. Research indicates that current erosion predictive models are valuable for estimating average sediment yield, but less effective for forecasting soil loss from individual slopes.

Key Findings

- In the coarse soils studied on the Colorado Front Range, post-fire erosion rates declined to near-background levels in five to eight years after the fire on most slopes.
- Most post-fire erosion occurs during the summer convective thunderstorm season, and little erosion is caused by snowmelt runoff.
- The key to reducing post-fire erosion is to maintain or rebuild ground cover. Thus, straw mulch was much more effective than the application of polyacrylamide (PAM) or scarification followed by seeding.
- A thick ash cover initially reduces soil loss. However, laboratory research confirms that following the second or third rainfall event, the benefit of the ash cover is lost and soil loss is essentially the same as in areas with no ash cover.
- Predictive models such as the Revised Universal Soil Loss Equation (RUSLE) and Disturbed Water Erosion Prediction Project (WEPP) are very useful for estimating "average" sediment yields, but less effective for forecasting soil loss on individual slopes.

Soils after the fire

Any fire in a forest, whether a wildfire or a prescribed burn, changes the environment. One area of obvious interest and concern is the soil. Consumption of trees, shrubs, forbs, grasses and forest litter by fire changes the susceptibility of the underlying soil to erosion. To have a fuller picture of the role of fire on erosion, and to understand how to control that erosion, managers need data.

A recent research project in the Front Range of Colorado makes significant contributions toward understanding the role of fire on soil erosion and sedimentation patterns. The Front Range is the geographical region within the Colorado Rocky Mountains that includes the first range of mountains encountered when going west from the Great Plains. It includes the prominent mountains immediately west of Colorado Springs, Denver, Boulder, Loveland, and Fort Collins.

Research on fire-influenced soil erosion and deposition is especially valuable in the Front Range because of the implications for water supply and recreational resources for the Front Range cities, which have an aggregate population of over five million. This project was conducted by principal investigators Dr. Lee MacDonald of the Department of Forest, Rangeland and Watershed Stewardship of Colorado State University, Fort Collins, CO; and Dr. Peter R. Robichaud of the Forest Service, Rocky Mountain Research Station of Moscow, ID. A significant amount of related project work was also done by graduate students from Colorado State University.

According to MacDonald, before the Joint Fire Science Program (JFSP) project, researchers were already making measurements in the Front Range on erosion and sedimentation resulting from four wildfires and three prescribed burns. The wildfires in 2002 raised awareness of not only the hazards from the fires themselves, but also of potential long-term effects on urban water supply, stream conditions, and erosion and sedimentation damage.

Robichaud notes, "This area has some of the highest erosion rates in the Western U.S. due to the coarse Pikes Peak granitic parent material, generally low ground cover and high intensity rain events." His observation is that with finer textured soils, there would be less erosion. "Finer-textured soils also often have higher levels of organic matter to bind the soil together."

Fires bring opportunities

The Schoonover wildfire started on May 19, 2002 and involved almost 4,000 acres of public and private land. The Hayman wildfire ignited on June 8, 2002 and over a period of 20 days burned 138,000 acres. This was the largest wildfire in Colorado history. On these two fire sites, researchers had fortuitously already established a series of erosion and sedimentation measurement sites. The JFSP project support allowed the team to compare various post-fire treatments and to expand and intensify monitoring in these test areas. Measurements continued until post-fire sedimentation rates had returned to near-background conditions.

Studies also included continued monitoring on 63 untreated control plots on these two fire sites and on plots at the 2000 Bobcat wildfire, the 2002 Hewlett Gulch wildfire, the 2003 Big Elk wildfire, and on hillslopes adjacent to the Schoonover wildfire that were burned in a prescribed burn in 2005. Researchers also used existing data from seven other wildfires and three prescribed burns, which gave a dataset of 422 plot-years of data from 110 untreated hillslopes. Additional laboratory studies were done to better understand field results.

By collecting and measuring actual soil volumes, calculations could be made on the relative effectiveness and persistence of various techniques for controlling soil erosion.

Comparing treatments

Burned Area Emergency Response (BAER) assessments are conducted after wildfires on federal and state lands and these assessments often prescribe post-fire treatments if there are values-at-risk they wish to protect. Treatments include a wide range of mulching, scarification, seeding, spraying and other erosion reduction techniques. One goal of this project was to apply a range of these BAER techniques and to compare the longer-term results with untreated control areas to determine the effectiveness of various treatments.

The Front Range fires studied were generally on coarse-textured soil types, which are susceptible to rill and channel erosion. Four surface treatments were tested on 18 pairs of treated and control hillslopes; plus four additional hillslopes were treated with aerial hydromulching. The treatments included:

1. Straw mulch surface cover.
2. Ground-based and aerially applied hydromulch including seed. The aerial hydromulch also included a polyacryamide (PAM) binding agent.
3. Shallow scarification with McLeod hand tools and seeding.
4. Surface treatment only with PAM, applied both as a dry powder, and as a wet solution that also included ammonium sulfate.

Some treatments worked, others did not

Results of the BAER treatments were mixed. Aerially applied straw mulch treatment was effective in dramatically reducing sediment production rates by more than 90 percent from the time of initial application in summer 2002 to summer 2003, and by 50–70 percent in summer 2004. The aerial hydromulch, which included a 70/30 mixture of barley and triticale seed applied at a rate of 70 pounds per acre, had some benefits during the first few rain events but then deteriorated and was washed downslope with subsequent rainfall events. Three years later, both types of mulch cover had deteriorated to the extent that there were no significant differences between treated and control sites.

Aerially applied straw mulch treatment was effective in dramatically reducing sediment production rates by more than 90 percent.

Of the various methods studied, aerially applied straw offered the best control of erosion.

Aerially-applied hydromulch, while initially effective, did not provide lasting erosion protection after the first two or three summer rains.

Two application methods of hydromulch, ground-based with trucks and aerially applied with helicopters were also compared. Compared with the aerial hydromulch, the ground-based hydromulch had higher water content, did not include a PAM binding agent, and had a lower seed density. Visual observations indicated that aerial hydromulch had a much stronger and cohesive surface cover. Four pairs of treated and control plots showed that the ground-based hydromulching did not reduce sediment yields or revegetation rates relative to the adjacent control plots.

Ground-applied hydromulch was even less effective than aerially applied hydromulch. It did not contain a binding agent and was not effective in reducing sediment yields.

Scarification and seeding

Another BAER treatment used was hand scarification using the McLeod hand tool, sometimes called a “fire rake,” along with a seeding treatment. The McLeod treatment scarified soil in burned areas to a depth of about one inch before seeding. This scarification and seeding was not effective in reducing sediment yields. Robichaud feels that deeper scarification would result in slightly better germination, but would also cause more soil movement via overland flow, so the result would not be greatly different.

Researchers concluded that the scarification and seeding had no significant beneficial effect on vegetative regrowth. Further, the shallow scarification did not increase infiltration in the soil, so runoff was not measurably reduced. Trials were also done using harrows pulled behind All Terrain Vehicles, which also proved to be an ineffective technique.

Testing application of PAM

Another BAER treatment that was tested was application of PAM to three hillslopes as a dry powder, and to three hillslopes as a wet solution that also contained ammonium sulfate. According to Robichaud, "the PAM was applied at rates recommended by the manufacturer." Studies indicated that there was no evidence that the dry PAM treatment reduced sediment production rates. Wet PAM treatment appeared to reduce sediment yields after two rainstorms in summer 2002 and one larger rainstorm in summer 2003, but the reduction was only significant for the events in summer 2002.

In order to confirm the results, the same wet PAM treatment was applied in June 2003 and June 2004 to the same three hillslopes that had received the unsuccessful dry treatment in 2002. This second treatment showed no significant reduction on sediment yields. A lab experiment showed that the PAM preferentially binds with ash, which helps reduce the erodible surface ash layer.

Researchers concluded that a heavier and carefully formulated application of PAM might provide some initial benefit in reducing post-fire erosion, but they do not support using PAM for post-fire treatment in this regime of coarse soils and frequent summer rains. Additional research is recommended to determine under what conditions (i.e., soil texture), application of PAM might have value for short-term reduction in post-fire erosion.

Thus, straw mulch seems to offer higher success for reduction of longer-term post-fire erosion control. The greatest difference with mulched areas versus untreated control areas is in the first two years. This is a significant benefit in many areas where revegetation is already well established by this time.

Slowly returning to normal

An important aspect of the research was long-term erosion and deposition monitoring. Most of the plots studied were areas of high severity fires. Measurement of sediment yields indicated that some sites approach background erosion rates by the third summer after burning. However, in many of the drier areas with coarse-textured soils, revegetation is much slower, so erosion continues at elevated rates. According to Robichaud, continued monitoring at the Hayman site indicated that even after six years, erosion rates had not reached background levels. He attributes the slower revegetation to the limited ability of these soils to retain soil moisture. Because of the widespread nature of the coarse-textured soils on the Front Range, these conditions are fairly common.

Robichaud feels that the research suggests that the preferred times of year for a prescribed burn from the perspective of minimizing erosion are when the fire won't consume the entire forest floor, which protects the mineral soil. "This is usually in the spring and fall. However, other ecological benefits might favor burning at other times."

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Wildfires cause severe erosion

Because of the demonstrated importance of forest floor cover material, researchers have learned that high-intensity wildfires can cause erosion rates at a magnitude greater than lower-intensity prescribed burns. Robichaud explains, "This is due to the complete consumption of the forest floor material and the creation of water-repellent soil conditions, which are common occurrences during a wildfire."

Effect of an ash layer

The evaluation of the site results indicated that the percentage of surface cover is an important determinant of sediment production. However, in order to have a clearer picture of the actual mechanism at work, additional experiments were done where researchers raked all of the litter from three unburned hillslopes and applied four artificial surface treatments: bare soil, a thin ash cover, a thick ash cover, and bare soil with a screen to reduce rain energy. Simulated rainfall was applied to the four treatments.

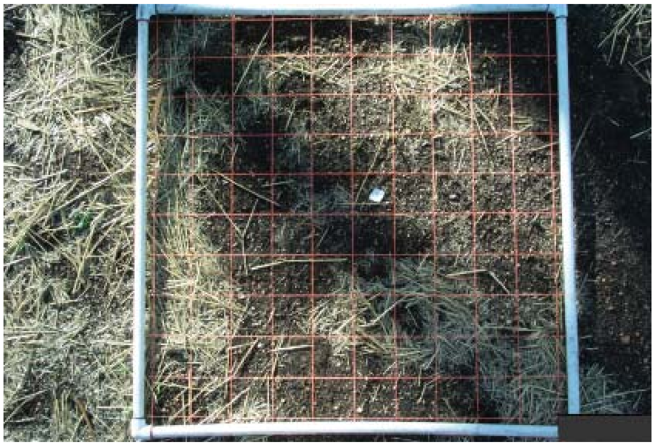
The results of this experiment demonstrated that rainfall at a rate of 1.6 inches per hour quickly caused a thin structural seal to form on bare soil plots, and these plots had the highest runoff rates. The presence of ash reduced surface runoff and larger reductions were observed for the thicker ash layer. However, repeated rainfall simulations showed that this ash cover was rapidly removed, and by the second or third simulation, runoff and erosion rates were comparable to the bare soil areas.

In the field experiment with raked removal of surface cover, the unburned raked plots produced just as much sediment as the plots that had burned at high severity. The experiments demonstrate that the high post-fire runoff and erosion rates are primarily due to the loss of surface cover and subsequent soil sealing, and that soil water repellency is a contributing factor. This explains why the BAER treatments that provide immediate ground cover are the most effective in reducing post-fire runoff and erosion rates.

Tool for better predictions

Data collected with the project allowed researchers to develop, test and validate different models for predicting post-fire erosion. One graduate student, J. Pietraszek, used half of the hillslope erosion data to develop an empirical model to predict post-fire erosion from untreated sites, and then validated the model against the other half of the datasets. Tests of these empirical models indicated that they were relatively poor predictors of post-fire erosion from another fire in the same region.

Data from untreated sites was also used to test the Revised Universal Soil Loss Equation (RUSLE) and the Disturbed Water Erosion Prediction Project (WEPP). Neither model was able to accurately predict post-fire sediment yields on a site-by-site basis. However, both provided reasonable estimates for "average" hillslopes. This was because of high variability among sites and challenges in representing all of these site characteristics. Both models tended to over-predict low erosion rates and under-predict high rates, again providing reasonable predictions for an 'average' hillslope.



Tools such as this 3 feet by 3 feet grid for determining percent mulch cover were used to accurately measure coverage effectiveness and persistence of the mulch cover.

Data on untreated, seeded and mulched hillslopes was used to validate the Erosion Risk Management Tool (ERMT)—a probabilistic, web-based model that uses the underlying WEPP technology. The results are consistent with those obtained with Disturbed WEPP. It tends to under-predict erosion rates for both untreated and mulched sites on the Colorado Front Range.

Projecting results to larger areas

Researchers also considered whether erosion rates measured at the plot or hillslope scale can be extrapolated to larger areas. This is important because larger scale measurement and replicated studies would be very expensive. In this study, data was collected from rainfall simulations on 1 square meter plots and on hillslopes ranging from 0.003 to 0.7 hectacre. Robichaud also collected data from six small watersheds of 3–5 hectacres. All of the sites are in the Hayman and Schoonover Fires areas and have similar slopes, soils and precipitation regimes.

Analysis of the results suggested that sediment yields from the small-scale rainfall simulations cannot be readily compared to the hillslope- and watershed-scale data. Efforts to normalize the data by precipitation amounts, rainfall intensity and rainfall erosivity have not been successful because the relationship between precipitation and sediment yields is non-linear and poorly defined for large storm events that do not often occur. Thus, the rainfall simulation studies, while useful tools for evaluating various factors, could not be extrapolated to larger areas.

One of the reasons it is difficult to extrapolate from hillslopes or small watersheds to larger areas in the Colorado front range is that rainfall from summer convective rainfall events can vary greatly over distances of just one or two kilometers. This makes projection of erosion or sediment yields to larger areas challenging. Numerous studies are continuing to increase our understanding of the post-fire environment.

Management Implications

- In evaluating erosion potential of wildfire or prescribed burn sites, the degree of consumption of forest floor organic material is a critical determinant of expected erosion levels.
- RUSLE and WEPP soil loss models have proven effective in forecasting 'average' hillslope post-fire sediment losses on the coarse soils of the Colorado Front Range but are not ideally suited for site-specific predictions.
- Of the various BAER treatments studied, straw mulching was effective in reducing soil loss after wildfire events. Hydromulch had mixed effects and deteriorated quickly. Scarification with seeding, and use of PAM surface treatments were not effective. These findings are specific to soils and conditions on the Colorado Front Range.
- The effect of an ash layer in reducing runoff and erosion rates is very temporary and most burned-over areas return to bare soil conditions after a few rainfalls.
- The coarse mineral forest soils on hillslopes of the Colorado Front Range may take six years or longer to return to background erosion rates following a wildfire.
- The optimum time for a prescribed burn from the perspective of minimizing erosion is in the spring or fall, when loss of organic ground cover will be minimized.

Further Information:
Publications and Web Resources

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Scientist Profiles

Dr. Peter Robichaud is a Research Engineer with the Forest Service Rocky Mountain Research Station in Moscow, Idaho. He, along with Dr. Lee MacDonald of the Department of Forest, Rangeland and Watershed Stewardship at Colorado State University in Fort Collins, Colorado, were the principal investigators on this group of projects. Dr. Robichaud is responsible for modeling and mitigation techniques of erosion from timber-harvested and burned areas in forest environments. His current research includes spatial variability, water repellent soil conditions, effects of prescribed burn and wildfire on erosion, and monitoring methods and mitigation techniques.

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Results presented in JFSP Final Reports may not have been peer-reviewed and should be interpreted as tentative until published in a peer-reviewed source.

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